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**The MayaArch3D Project:
Digital Technologies for Research in Maya Archaeology**

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FINAL PERFORMANCE REPORT AND WHITE PAPER

NEH DIGITAL HUMANITIES START-UP LEVEL II GRANT: #HD5097910

PROJECT TITLE: Digital Documentation and Reconstruction of an Ancient Maya Temple and
Prototype of Internet GIS Database of Maya Architecture

PROJECT DIRECTOR: Jennifer von Schwerin

GRANTEE INSTITUTION: University of New Mexico

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ABSTRACT

The MayaArch3D project is researching innovative approaches in digital technologies to make complex archaeological data available online for a wide community of researchers, cultural heritage managers, and the general public. Specifically, the project is developing and testing a prototype for a new platform for an online, searchable repository—called *QueryArch3D*—that can bring together GIS maps, 3D objects, and virtual environments for teaching and research on ancient architecture and landscapes.

This is an international, interdisciplinary project based at the University of New Mexico (UNM) (USA) that brings together art historians, archaeologists, cultural heritage managers with experts in remote sensing, photogrammetry, 3D modeling, databases, and virtual reality. The prototype tool, *QueryArch3D*, employs existing digital collections on Maya architecture from the UNESCO World Heritage Site of Copan (Honduras), as well as data produced specifically for this project at Copan with remote sensing technologies, including a highly-accurate, hybrid 3D model of an eighth century temple.

With help from a National Endowment for the Humanities Digital Humanities Level II Start-Up grant (\$49,832), Phase II project activities commenced April 1, 2010 and ended March 31, 2011. (Phase I of the project was funded by an NEH Level I Start-Up grant in 2009 (von Schwerin et. al 2010).) Phase II project activities are presented here, in which the project researched and demonstrated the workflow and technological pipeline necessary to build the full-fledged *QueryArch3D* tool and a prototype has been created. The project also created 3D models that would work in *QueryArch3D* in order to test and demonstrate the platform's capabilities. By September 2011, this beta-version –along with the 3D models created by the project—will be available online for testing and review on a new website that will be hosted by UNM (www.MayaArch3d.unm.edu).

The deliverables for the grant are: (1) the prototype tool hosted on the beta website that will be launched in September 2011, (2) this white paper that presents the project's goals and objectives, findings, accomplishments, and next steps, and, (3) publications and professional presentations.

The project outcomes show that NEH's initial investment has yielded great benefit in the form of international collaboration, project infrastructure, knowledge transfer, additional project funding, and a new prototype tool that offers innovative methods for digitally-based art historical and archaeological analyses of ancient architecture and landscapes.

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PROJECT HISTORY

The MayaArch3D Project emerged in 2009 when Dr. von Schwerin (PI) and Dr. Richards-Rissetto came together to realize a common goal.

2001-2008: Data Collection, Initial Research Projects, and Needs Assessment

Dr. Jennifer von Schwerin's (prev: Jennifer Ahlfeldt) ideas for a 3D database of Maya architecture grew out of her work on a project she began in 1998 as her dissertation research at Columbia University's Department of Art History and Archaeology—the Temple 22 Façade Sculpture Reconstruction Project at Copan, Honduras (Ahlfeldt 2004). Copan's thirteenth ruler - King Waxaklajuun U'baah K'awiil (reigned AD 695-738) commissioned Temple 22 inside the Acropolis of Copan, which has over 3500 fragments of mosaic facade sculpture now housed both in Honduras and museum collections around the globe. The most famous of these is the Maya Maize God, now at the British Museum. In collaboration with archaeologists at Harvard University and with funding from Columbia University, the Whiting Foundation, the Metropolitan Museum of Art, UNM, and private foundations, von Schwerin has led fieldwork under the aegis of the Honduran Institute of Anthropology and History (IHAH) to analyze and reconstruct Temple 22's façade sculpture consisting of almost 4000 pieces. This resulted in her dissertation, *On Reconstructing and Performing Maya Architecture: Structure 10L-22, Copan, Honduras (AD 715)*, completed in 2004. To visualize and test her temple reconstruction, she directed prototype 3D models in 2001 and 2005. These were not completed, both due to lack of funding and expertise on how to scan individual sculptures to place onto the 3D model.

Meanwhile, during the course of her dissertation work at the University of New Mexico's Department of Anthropology, Dr. Richards-Rissetto constructed a GIS database of Copan's archaeological features and a 3D (SketchUp) model of the city's urban core for access and visibility studies. She scanned, geo-referenced (assigned real-world coordinates), and digitized maps covering 24 square kilometers of the Copan Valley. The GIS contains several base layers (shapefiles) of archaeological features, modern features, and natural features linked to attribute data. It also contains raster data including a Digital Elevation Model (DEM) and Urban DEM (integrating archaeological and natural features into a single surface), viewsheds, and cost surfaces.

Together they realized that, although their projects are at different scales, they had similar goals:

- 1) to do archaeological research at Copan across multiple scales and different 2D and 3D data formats,
- 2) to explore the research value of 3D data for art historical and archaeological method and theory, and
- 3) to explore the potential of 3D data for cultural heritage practices in Honduras.

2008-2009: Identification of international partners and project feasibility discussions

The participants met in 2008, when the University of New Mexico and the Alexander von Humboldt Foundation granted Dr. von Schwerin funding to develop this project, as well as to travel to Ascona (2008) and Zurich (2009) for initial meetings, training in 3D data acquisition technologies, and planning.

Professor Gruen's team at ETH, Zürich and Fabio Remondino's team at FBK, Trento have the ability to generate high-quality 3D models of ancient architecture and to optimize them for a web environment. They use a variety of sensors and methods (laser-scanners, structured light systems, and an Unmanned Aerial Vehicle—a model helicopter). In 2008, von Schwerin, Gruen, and Remondino agreed to collaborate and in January 2009, von Schwerin and Richards-Rissetto traveled to ETH Zürich for two weeks of training on the modeling and optimization options.

March 2009 – April 2010: Start-Up Project Phase I: Environmental Scan and Project Planning:

It is under these circumstances that UNM applied for and received a NEH Level I Digital Humanities Start-Up grant (PI: von Schwerin) to support two international workshops in Copan, Honduras and Zurich, Switzerland. The goals of these workshops were to bring together archaeologists, art historians, cultural heritage managers and technology specialists to (1) determine research and cultural resource management needs, (2) to complete an environmental scan of the state-of-the art research in 3D archaeology in Honduras and 3D technologies, (3) to plan the development of the prototype tool—*QueryArch3D*, and (4) to collect initial field data to create 3D models for testing in this tool (Remondino et. Al 2009).

The result of these international workshops showed us—that in order to reinvent how we integrate our data for the research we envision, three components are needed: 1) 3D objects, 2) virtual reality environments, and 3) GIS in a single, open-source web environment. In other words, research and development of 3D Web GIS tools is needed. Workshop participants identified the need for online tools that store, edit, query, and analyze multi-resolution, geo-referenced 3D models in a navigable environment. Everyone agreed that such tools would significantly enhance research and teaching on ancient architecture and help to educate the public and to manage information; however, no such tools existed.

The MayaArch3D Project was thus formed, and partners determined that to develop such a tool, the next phase of the project needed to establish the pipeline for creating 3D models that would work in this platform, and then build the platform and test and demonstrate the platform's capabilities.

While in Honduras, in addition to identifying the need for developing a 3D Web GIS tool for research and teaching on ancient architecture and landscapes, project collaborators collected 3D data to use as sample data in *QueryArch3D* (Remondino et al 2009; von Schwerin et al. 2010). UNESCO contributed \$20,000 to assist with 3D data collection in Copan. An initial reality-based model of Temple 22 and the East Court at Copan was made by

our collaborators at ETH Zurich from close-range photogrammetric images taken from a remotely-controlled helicopter. 3D models of stelae and reliefs were also made by FBK Zurich by time-of-flight scanning. A full report of the results from the Phase I Start Up project is available in a NEH White Paper (von Schwerin et. al 2010).

STATE OF THE FIELD

Modern sensor and computing technologies are changing the practice of art history and archaeology because they offer innovative ways to document, reconstruct, and research the ancient world in three dimensions (e.g., El-Hakim et. al 2008; Reindel and Wagner 2009). State-of-the-art imaging technologies allow researchers to document 3D objects to the level of the micron (e.g., Gruen 2008) while Virtual Reality (VR) simulation programs enable reconstructions of ancient buildings in their ancient environments and landscapes. The broad interest in this field is seen at conferences such as CAA (Computer Applications and Quantitative Methods in Archaeology), ISPRS (International Society for Photogrammetry and Remote Sensing), and the recently founded online, peer-reviewed journal –SAVE (Serving and Archiving Virtual Environments) that is dedicated to publishing 3D digital models of the world’s cultural heritage (CH) sites and monuments. Our project is concerned with a subset of this field—the development and testing of new online tools that link 3D models technologies and GIS for spatio-temporal analyses of ancient architecture and landscapes.

Current Projects using 3D Models and GIS for Analysis

With regard to architecture, researchers developing tools for viewing and analyzing sophisticated 3D architectural models include the two big academic VR environment recreation labs—the Experimental Technology Center (Diana Favro) at University of California, Los Angeles (UCLA) and the Institute for Advanced Technology in the Humanities (Bernard Frischer) at the University of Virginia (UVA), who have collaborated on the project “Rome Reborn”. In Europe, 3D models of architecture are often used for the analysis of building plans and phases (for instance the DAI project on Roman emperor palaces in Rome and Serbia (Weferling et al 2001; Wulft 2004) and analyses of the Cologne cathedral (Lengyel 2010)), or for virtual reconstruction and visualization of ancient cities.¹ More recently, a few researchers have begun to explore how digital models might be used for comparative online research. Stephen Murray’s *Mapping Gothic France* project—a collaborative project linking text, QTVRs, and 2D and 3D images to an interactive map of Gothic cathedrals—is one example.

Geographic Information Systems (GIS) support comparative analyses of relationships and changes over space and time, for example, by bringing together buildings, sculpture, and artifacts into an integrated landscape for comparison and analysis (e.g., Conolly and Lake 2006; Lock and Stancic 1995; Lock 2000; Wheatley and Gillings 2002). Archaeologists began to use GIS in the 1980s, predominantly as a data management system—to create, manage, analyze, and visualize geographically referenced information and reveal complex relationships, patterns, and trends that are not evident when using traditional, or non-spatial, databases. Early research applications focused on analyzing artifact distribution within sites, or predicting archaeological site locations. More recently, archaeologists have begun to use visibility, accessibility, and network analyses in GIS to explore the structure and organization of human societies and relationships between anthropogenic and natural phenomena (Conolly and Lake 2006; Llobera 2001, 2006; Richards-Rissetto 2010, in press).

¹ <http://www.colonia3d.de/>

Using geomatics, researchers integrate GIS and airborne remote sensing to reconstruct topographic landscapes (e.g., Eisenbeiss 2010, Lambers et al. 2007; Posluschny 2007, Saturno et al. 2007).

Some of the first experiments in 3D Web GIS include that of Maurizio Forte and his team in Italy, who 2004-2007 carried out the Via Appia Antica Project — developing a specific tool in Open Scene Graph (Forte et al., 2005). In this project, they integrated topographic landscapes with 3D architectural models in a VR environment (e.g., Virtual Rome) to offer interactive virtual exploration and multi-perspective experiences. More recently, Forte has been working at Catal Huyuk, Turkey to link GIS layers of archaeological excavations with 3D models (Hodder and Forte 2011).

3D Applications in Maya Archaeology

While many 3D applications have focused on Classical civilizations, in the last decade, researchers have begun to explore how such tools might be used for research on the ancient civilizations of the Americas. Previous workshops dealing with 3D archaeology in the Americas include a conference organized by Reindel in 2007 about new technologies in archaeology (Neue Technologien für die Archäologie: der Projektverbund Nasca, Peru), which resulted in the book “New Technologies for Archaeology: Multidisciplinary Investigations in Palpa and Nasca Peru” (Reindel and Wagner 2009), and a workshop organized by von Schwerin in 2009 about 3D Archaeology and Cultural Heritage in Honduras (proceedings are in press).

Current 3D projects dealing with the remains of the ancient Maya civilizations of Mexico and Central America include those that are engaged with high-resolution scanning of individual sculptures for conservation and study purposes—such as the Mesoamerican Sculpture Database Project (Doering and Collins 2009), Harvard’s Corpus Project (Hieroglyphic Stairway Project) (Barbara Fash 2011, in press; Tokovinine and Fash 2008), and INAH’s AJIMAYA project (Pallán 2009; Grube, Pallán and Benavides 2009, 2010; Roman-Rangel, Pallán, Odobez, and Gatica-Perez 2009; 2011).² In terms of making 3D data available for online-access and analysis through specific tools, the only website with a searchable database of 3D models is that of the Foundation for the Advancement of Mesoamerican Studies (FAMSI). Meanwhile, other groups like CyArk and Maya Skies create 3D reconstructions and animations of entire buildings, and archaeologists often hire students or architects to make 3D simulations of Maya temples.

With regard to larger landscape contexts of ancient Maya kingdoms, remote sensing and GIS are playing important roles. Remote sensing technologies such as satellite imagery and airborne LIDAR have been used to facilitate archaeological prospecting and offer new understandings of ancient Maya sites, such as at Copan (e.g. Gutierrez 2001), Caracol (Chase et al. 2011), and San Bartolo (Saturno et al. 2007). Researchers at the Slovenian Academy for Sciences and Arts and the Institute of Photogrammetry and Remote Sensing at the Vienna University of Technology applied GIS and aerial photos to predict site locations in the

² <http://www.gobiernodigital.inah.gob.mx/mener/index.php?id=12>
<http://www.arqueologia.inah.gob.mx/proyectos/agimaya/#nogo>
<http://www.idiap.ch/project/codices>

Yucatan peninsula (Podobnikar and Sprajc 2010). In the Maya area, archaeologists from Boston University used GIS for visibility studies to reconstruct site lines between urban temples and outlying stelae at the Maya site of La Milpa in Belize (Hammond and Tourtellot 1999), and GIS data on Copan's architecture within its topographic landscape (Richards-Rissetto 2010), or Tom Garrison's boundary studies in the Triangulo area (2011). GIS—linking maps to searchable databases—are able to support interactive analyses of relationships and change over space and time, and allow for multi-scalar analyses. The Electronic Atlas on Ancient Maya Sites housed at Florida Atlantic University and Longwood University (USA) uses GIS as a repository to store the locations of Maya archaeological sites and to create maps that overlay these sites on terrain, hydrology, or other features to illustrate polity size, political boundaries, etc.³

Current Challenges to Developing 3D Web GIS Tools

The issue that our project concerns itself with, however, is that most of these 3D models are single objects, removed from the context of their place in an urban landscape. These are not linked to GIS data, nor are they available within a VR environment, and most importantly, they are not measurable or comparable with each other in any way.

Nowadays 3D models of large and complex archaeological sites are generated using methodologies based on image data, range data, classical surveying or existing maps. The choice depends on the required accuracy, object dimensions and location, the surface characteristics, the working team experience, the project's budget, the final goal, etc. These result in 3D models in various ranges of details and resolutions. Increasingly, the different methodologies are combined to derive multi-resolution data of archaeological sites at different levels of detail (LoDs), both in geometry and texture. This combination of multi-resolution data can expand research opportunities for ancient architecture and landscapes.

One promising opportunity offered by 3D models is to use them as visualization “containers” for different kinds of information. Given the possibility to link their geometry to external data, 3D models can be analyzed, split into sub-components, and organized following proper rules. Powerful 3D visualization tools already exist, but often they implement no or only limited query functionalities for data retrieval, and very few of these are web-based. In contrast, GIS packages include queries as standard functions. GIS software, however, falls short when dealing with detailed and complex 3D data (e.g., ArcScene—ESRI ArcGIS tool for 3D visualization). Probably one of the most well-known examples is Google Earth, a GeoBrowser in which users can browse through geospatial data and retrieve external information by clicking on selected objects, or by activating a selectable layer. However, more complex, interactive queries are not implemented in Google Earth. It is not possible, for instance, to select all structures in a city/site built between a certain time intervals, or planned by a certain architect/ruler. The ability to perform such interactive queries in a 3D online environment would significantly enhance research and education of ancient architecture and landscapes; however, such functionality did not exist until the development of the *QueryArch3D* tool.

³ <http://mayagis.smv.org/>

Therefore, the driving question behind von Schwerin and Richards-Rissetto's current research is how to link 3D models of reality-based or virtual reconstructions to a GIS database that would allow comparisons and analyses between visualizations of buildings and artifacts from different cities (von Schwerin et al. 2010). Is it possible to create a central place for researchers of Maya architecture where they can compare and study 3D reconstructions in the context of geographically referenced urban landscapes? We are interested in tools not only for recording and visualization, but also for analysis. 3D documentation is not only a new kind of very accurate, complete and realistic method of documentation, but necessary for advanced types of spatial analysis provided through GIS (line of sight analysis, viewshed analysis, volumetric analysis, cost analysis, etc.)—approaches that add value to traditional investigations. Another innovative part of our research is to explore tools for online, real-time analyses of multiple types of 3D data, and to figure out how to make highly accurate 3D models archaeological data, and GIS data accessible through a collaborative VR environment.

PROJECT GOALS AND OBJECTIVES

In 2010, the University of New Mexico (Project PI: von Schwerin) received NEH Digital Humanities Start Up Level II funding to develop the next phase of the MayaArch3D Project.

The goal of the MayaArch3D Project is to research the possibilities of 3D technologies for studies of ancient architecture and urban landscapes, and specifically how to make 3D models and GIS data available online for research, teaching, cultural heritage management, and public education. The project brings together art historians and archaeologists from the University of New Mexico (UNM), site managers from the Honduran Institute of Anthropology and History (IAHA), and technology specialists from ETH Zurich, the B. Kessler Foundation in Trento (Italy), and the University of California, Merced.

The MayaArch3D Project has four components—GIS, 3D models, databases, and virtual reality. In this phase of the project we have established and tested a pipeline for bringing together these components into a prototype tool: *QueryArch3D*. This tool will enable users—in a single online, navigable virtual reality landscape—to:

- 1) Integrate 2D and 3D data of multiple resolutions,
- 2) Perform attribute and spatial queries of archaeological data, and
- 3) Compare and analyze 3D buildings and artifacts

The main objectives of this Start-Up Level II grant were:

- 1) to develop the prototype tool *QueryArch3D* – a 3D Web GIS tool that curates (in a searchable and virtual environment) 2D and 3D digital collections of data on ancient Maya architecture from Copan,
- 2) to continue to create the most highly-accurate, hybrid 3D model of an ancient Maya temple and its architectural sculpture to date,
- 3) to optimize this and other models in order to integrate multi-resolution data from multiple sources for online use in *QueryArch3D* and for use in a Teleimmersive Collaborative Environment (VR) being developed by Maurizio Forte at UC Merced, and
- 4) to determine and establish a pipeline for how the different components (hybrid 3D model, 3D Web GIS database, VR environment) of the larger project will function together. Once we know the limits and possibilities of the tools, we can better plan subsequent data collection efforts.

To accomplish these objectives, we addressed the following questions:

- 1) How can we link different data types (e.g., text, 2D images, and 3D models) into a single tool that combines GIS and VR management capabilities?
- 2) How can we link data of different resolutions (e.g. high vs. low) into a single tool?

- 3) How can we make this tool accessible online and in an efficient way so that people with slower bandwidths can access?
- 4) What type of pre-existing software can we use?
- 5) How can we import/export data across different platforms (software) to use in the prototype tool?
- 6) What data are required for development purposes?
- 7) What types of functionality from the project's four components can we add to the prototype tool?
- 8) What new functions are possible in the prototype tool?
- 9) What are the specific research questions that the prototype can test?
- 10) What is the pipeline for creating a hybrid 3D model of a reconstructed temple that can be used in multiple platforms, e.g., QueryArch3D, UC Merced Teleimmersive Collaborative Environment, and Stellarium?

Case Study – Copan, Honduras

Our case study is the UNESCO World Heritage site and ancient Maya kingdom of Copan (Figures 1 and 2), and our aim is to carry out multi-scalar research to reveal spatial patterns that will help us investigate the impact of Copan's architecture and landscape on ancient social experience in the 8th and 9th centuries between the reigns of the 13th and 16th rulers.

The prototype tool focuses on collections of data at Copan. Copan offers ideal research possibilities for 3D data analysis, for there is simply a great deal of available data to analyze in new ways. This long history of research and excavation at Copan (since the 1840s) has played a key role in shaping our understanding of the Maya world.

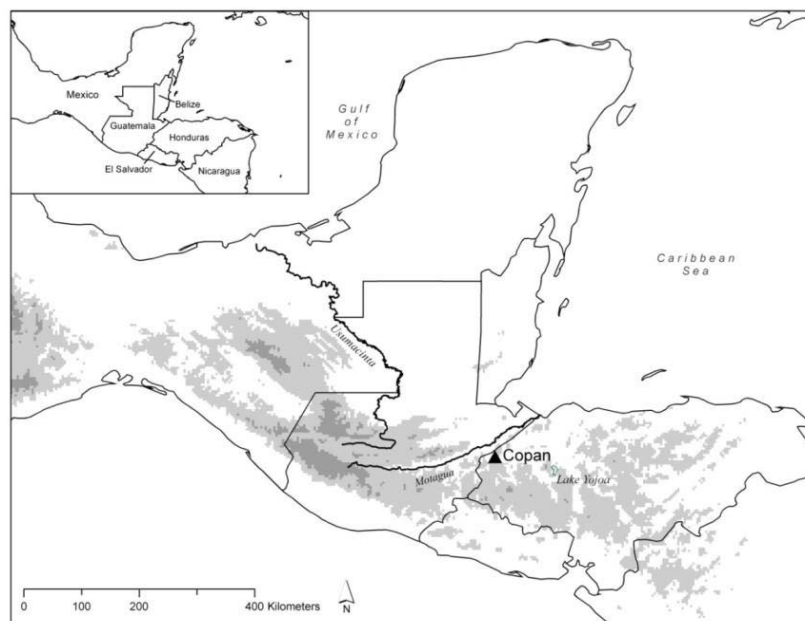


Figure 1. Location of Copan in Mesoamerica



Figure 2: View of remains of Temple 22 in Acropolis (von Schwerin photo)

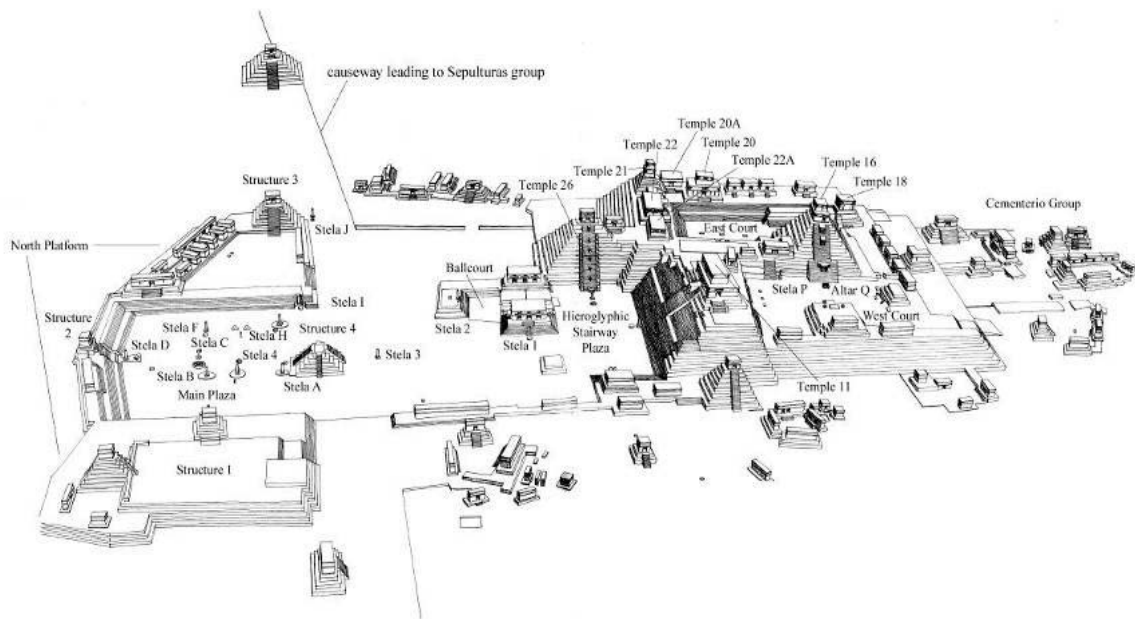


Figure 3. Reconstruction of eighth-century center of Copan, Honduras (from Hohmann and Vogrin 1982).

Archaeologists have shown that the kingdom had a dynasty of sixteen kings that ruled over five centuries (AD 427-822) (e.g. Andrews and Fash 2004; Fash 2001). Its location at the southeast periphery of the Maya world made it a center of commercial and cultural exchange. Although countless individual structures at Copan have been thoroughly excavated and documented over the last century, there is still much work to do in order to examine the building campaigns of various rulers as a whole, and in comparison with each other. Our project focuses on the eighth and early ninth centuries—a period that saw two major urban building campaigns of the 13th and 16th rulers.

Archaeological Research Applications

By integrating the data and functionality of databases, GIS, 3D modeling, and virtual reality, in the *QueryArch3D* tool, we seek to perform distance-dependent and spatial queries, and for example, analyses of directionality, aesthetic experience, and access and visibility. We plan to use this tool to carry out a multi-scalar visual and spatial study of Copan's entire urban landscape in order to investigate the ideological and socio-political factors that underpinned the changes in temple and urban design that occurred at Copan over the last two centuries of the kingdom's history. We address specific questions such as: What was the relationship between civic and domestic architecture at Copan? Are expressions of Maya cosmology apparent in the urban landscape?

To address these questions, we are designing the tool to perform such functions as:

1. Query, compare, and analyze 3D models of architecture and attribute data (such as photographs, maps, drawings and models of sculpture, mural, ceramic, and other archaeological data) in a virtual landscape context.
2. Measure architecture
3. Calculate visibility
4. Determine directionality

While our research questions have determined our database design and *QueryArch3D*'s current functionalities, the tool can be tailored to other conceptual frameworks and additional functions can (and will) be added.

Cultural Heritage Management Applications

The *QueryArch3D* tool is also for cultural resource management. Not only can resource managers and archaeologists store, manage, and query data about archaeological sites in the Copan Valley—all features available in traditional databases—but they can also easily locate, enter, and access information on objects and buildings both in and out of the archaeological park in a navigable virtual environment. *QueryArch3D* provides user not only with 3D models of archaeological sites and access to data via these models, but the tool places these models within a broader spatial context. Using these tools, resource managers can overlay archaeological and modern data and thus use both sets to query, for example, all sites located within 15 meters of a water source in order to identify sites that may have a high-risk for erosion. These same data are useful in identifying sites that may be located in new construction zones. Along these lines, such functionality can help cultural resource managers to locate sites in the physical landscape for site assessment and other purposes. Furthermore, excavations records could be linked to the 3D models to provide an interactive visual tool for querying information about past excavations.

Teaching and Public Education Applications

The *QueryArch3D* tool is suited to today's youth—visual learners who are intrigued, excited, and proficient in using interactive and dynamic technologies. The tool is being developed for multiple levels of accessibility and with multiple types of media (panoramas, photos, videos, etc.). Teachers, for example, could use guided virtual tours, with stops to access multimedia content (videos, maps, etc.), to teach students about indigenous concepts of space and time as well as ancient uses of architecture and landscape. Teachers and students could also link to unrestricted parts of the database to query, compare, and analyze architecture in a landscape context. As for public education and outreach, the possibilities for online and actual exhibitions are multiple and the project has had several inquiries from museums and is exploring options.

In order to serve these multiple purposes—research, cultural resource management, teaching, and public education/outreach, we have organized the pipeline for the *QueryArch3D* tool into four components—GIS, 3D models, virtual reality and databases. The next section describes the work completed in the context of these four components and then discusses the *QueryArch3D* tool.

WORK COMPLETED TO DATE:

As stated above, the MayaArch3D Project has four components—GIS, 3D models, virtual reality and databases. This section reports on the workshops at which decisions about these components were made, and also describes each of these components and the particular data they contain, the work that was carried out under this grant on them, and explains how they relate to the *QueryArch3D* tool.

A. Workshops

Freiburg, Oct. 31st - Nov. 2nd, 2010

In early 2010, Jennifer von Schwerin and Heather Richards-Rissetto, an archaeologist and post-doctoral researcher at HUMlab, Umeå University, Sweden, began working with Fabio Remondino and Giorgio Agugiaro at the FBK Research Institute to develop a prototype platform for *QueryArch3D*. They met in person October 31st - November 2nd, 2010 to report on project work to date and to create the conceptual model for *QueryArch3D* and a segmented model of Copan's Principal Group and Temple 22, and on modifying the database and its attributes to accommodate the segmented model.

Bonn, May 17th -19th, 2011

Project partners met with each other at the Department for the Archaeology of Non-European Cultures of the German Archeological Institute in Bonn, Germany, and at the Department for Cultural Anthropology of the Americas at the University of Bonn to give public lectures and also to report on the work completed under the terms of the grant, its accomplishments and challenges, and to identify future directions, and further funding possibilities. This workshop was funded by a DAAD grant (German Academic Exchange Service) to the University of Bonn.

B. Project Components and the pipeline

This section explains the various project components, the data from Copan that are included, and the pipeline for bringing them all together.

I. Geographic Information Systems (GIS)

Dr. Richards-Rissetto created the project's GIS by scanning, geo-referencing (assigning real-world coordinates), and digitizing paper maps of the Principal Group and valley sites ranging in scale from 1:100 to 1:2000 (Fash and Long 1983; Hohmann and Vogrin 1982; Hohmann 1995). The GIS covers 24 square kilometers and contains data on: 1) archaeological structures, 2) stelae and altars, 3) hydrology, 4) contour lines, 5) modern roads, 6) a Digital Elevation Model (DEM), and 7) an Urban DEM that integrates Copan's terrain and built environment (including 3000 plus structures). The GIS also contains attribute data on structure names, group names, site type, building heights, building elevation (as masl), hydrological features, and modern roads as well as information for the Principal Group structures such as construction dates and associated ruler (Figure 4).

The sources for these GIS data are many. They include maps, architectural drawings, and attribute data from 1) the Principal Group or "Civic Ceremonial" Group (e.g., Gordon 1986,

Graham 1963, Hohmann and Vogrin 1982, Stephens 1841, Stromsvik 1947) and, 2) “domestic” sites in the Copan Valley (e.g., Hendon 2010; Hohmann 1995, Sanders 1986, Webster 1989; Willey et al. 1978; Willey and Leventhal 1979).

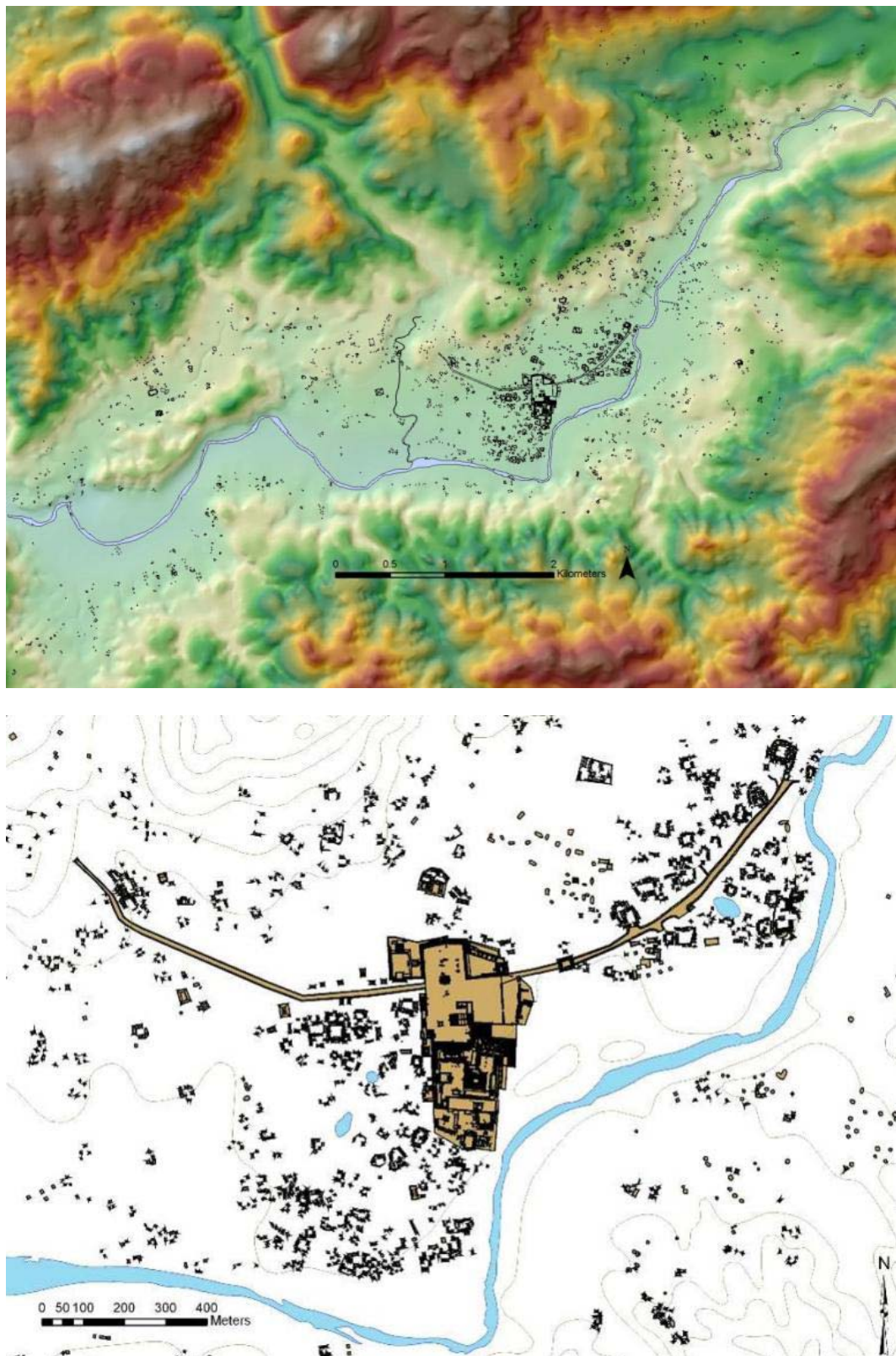


Figure 4. Maps from Copan GIS developed by Heather Richards-Rissetto. (Top) Sites in Copan Valley, (Bottom) Structures in Urban Core including Main Civic-Ceremonial Complex

The base shapefiles for the GIS come from the Proyecto Arqueológico Copan (PAC I) archaeological survey that mapped 100% of the archaeological remains in the Copan Valley and published 24 one-square kilometer maps with data on archaeological sites, contour lines, and waterways (Fash and Long 1983). While data is periodically added to the Copan GIS, the base shapefiles and Digital Elevation Models are complete and are currently available for research purposes.

Using these data, and standard GIS software such as ArcGIS, we can perform multi-criteria attribute and spatial queries as well as quantifiable analyses. While GIS is ideally suited for spatial analysis, its reliance on 2.5D data (stored heights and elevations in an attribute table) limits the scope of ancient landscape studies. GIS maps limit researchers to a flat, two-dimensional perspective that fail to adequately capture ancient experience. The ability to carry out three-dimensional analyses is important, for example, for studies on the ancient Maya, who viewed the world as multi-layered, and physically incorporated these many layers into their built environment to influence social experience and sociopolitical relations (e.g., Ahlfeldt 2004; Ashmore 1991; Coggins 1980; Richards-Rissetto 2010, in press). However, current 3D Web GIS tools do not link GIS data to 3D models in an interactive online environment. The MayaArch3D Project is using the Copan GIS data to develop and test the pipeline for creating such a tool, i.e. *QueryArch3D*.

The GIS data serve three major purposes in the *QueryArch3D* tool.

- 1) GIS data were integrated into the *QueryArch3D* tool,
- 2) GIS data were converted from 2.5D data into 3D prismatic models used as the interface for the prototype *QueryArch3D* tool, and
- 3) GIS data are being used to create more detailed and realistic low resolution 3D models for a VR landscape that will eventually serve as the interface for *QueryArch3D*.

The first two purposes are discussed in this section and the third purpose is discussed in the Low Resolution Models of Section II.

Purposes 1: Before we could integrate the GIS data into the *QueryArch3D* tool, we had to establish the conceptual framework for the database and a hierarchical scheme for segmenting the architecture (see the Database and *QueryArch2D* sections for more details). For example, all attributes had to be assigned in a correct and consistent way.

Purpose 2: In order to transform 2.5D GIS data into 3D prismatic models, and to group them according to the chosen hierarchy criteria, both the attributes and geometry had to be checked for errors and inconsistencies. For example, in relation to geometry, there could be no sliver polygons (invalid gap or overlap along borders of polygons) or missing values in the attached attribute table.

In the future, any new GIS data will be created to adhere to these above requirements established in the pipeline so that they can easily be integrated into the *QueryArch3D* tool.

II. 3D Models

One objective of the MayaArch3D Project acquires, creates, and integrates both low and high resolution 3D models for Copan to test and demonstrate the platform's capabilities. They include:

a. Low Resolution Model of Copan – SketchUp

Dr. Richards-Rissetto is using the Copan GIS data to create low resolution models of Copan's architecture. She is using Google SketchUp to create these models for five reasons.

1. GIS data can be exported from ESRI ArcGIS into Google SketchUp meaning that the SketchUp models are geo-referenced.
2. SketchUp offers a fast and efficient way to create building templates that can be modified (including scaling) to building footprints.
3. Architectural elements (e.g., stairs, platforms, wall, roofs) can be organized as components (of different sizes, construction materials, etc.) and these components can easily be interchanged providing a quick way to test building designs and site organization.
4. SketchUp offers a way to model architecture at the level of landscape.
5. Using SketchUp Pro the models can be exported into several formats that can be used in landscape visualization programs, in UC Merced's collaborative environment, and in the *QueryArch3D* tool

The SketchUp reconstruction is of Copan's early ninth century landscape following a major urban renewal project commissioned by *Yax Pasaj*, the kingdom's 16th and final dynastic ruler, and just prior to the breakdown of political authority. The model consists of two categories of sites—the Principal Group and the valley sites. For both categories, geo-referenced building footprints and base elevations (masl) are exported from ESRI ArcGIS into Google SketchUp. The Principal Group is modeled directly from the GIS data using the heights of stairs, platforms, and buildings included in Hohmann and Vogrin's (1982) architectural maps and drawings—second stories, roof combs, and doorways are then manually reconstructed in SketchUp (Figure 5).

As for the valley sites, there are five types. These types are based on the Harvard Site Typology that uses architectural criteria to classify Copan's sites (Willey and Leventhal 1979; Willey et al. 1978). They are: 1) auxiliary structures, 2) Type 1, 3) Type 2, 4) Type 3, and 5) Type 4. Figure 6 illustrates the construction materials used for each type, which range from pole and thatch for auxiliary structures to mud-colored adobe and thatch roofs for type 1 and type 2 structures to plastered ashlar masonry with thatch roofs for type 3 structures to plastered ashlar masonry with corbel-vaulted roofs for type 4 structures (Abrams 1998; Gonlin 1993; Hendon et al. 1990). To correspond with the Harvard Typology's criteria of mound height, type 3 and type 4 structures, typically considered elite, are taller than type 1

and type 2 structures. Of course, there are many more formal variations to these structures than we have made models for—an obvious example is the tri-partite floor plan. However, due to the time-consuming nature of creating, placing, and scaling these models, at the moment we are just using these templates.

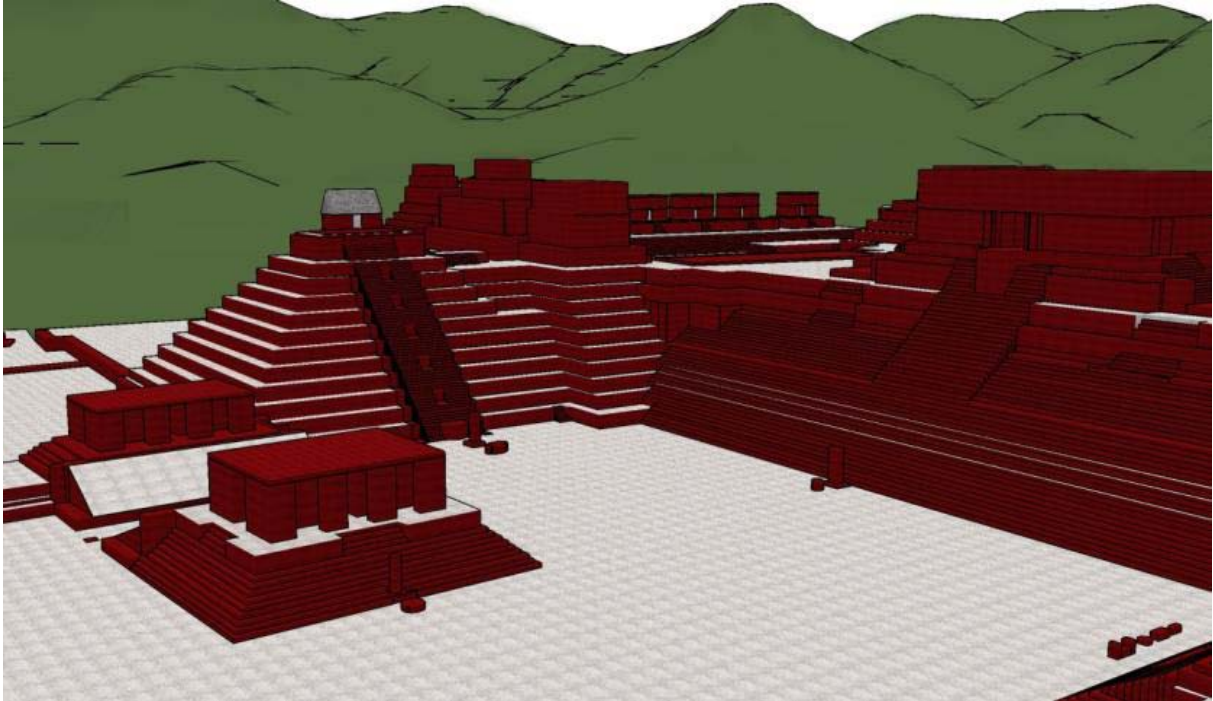


Figure 5. SketchUp Reconstruction of Copan's Principal Group



Auxiliary



Type 1



Type 2



Type 3



Type 4

Figure 6. SketchUp Reconstructions of Copan's Site Types

Reconstructing Copan's architecture is an ambitious task. This is the first reconstruction of an ancient Maya city that extends beyond the city center to incorporate both urban suburbs and countryside communities. Our goal is to create low resolution (SketchUp) models for the 3,000 plus structures that surround Copan's civic-ceremonial center (and cover 24 square kilometers). The current status of the SketchUp model is:

- 1) We have created models for most of the Principal Group's major temples.
- 2) We have created platforms and are in the process of creating superstructures for the Principal Group's other buildings.
- 3) As for the valley sites, we have created models for many of the structures in four urban suburbs (El Bosque, Las Sepulturas, El Comedero, and Salamar) (Figure 7) approximately 750 structures have been modeled.

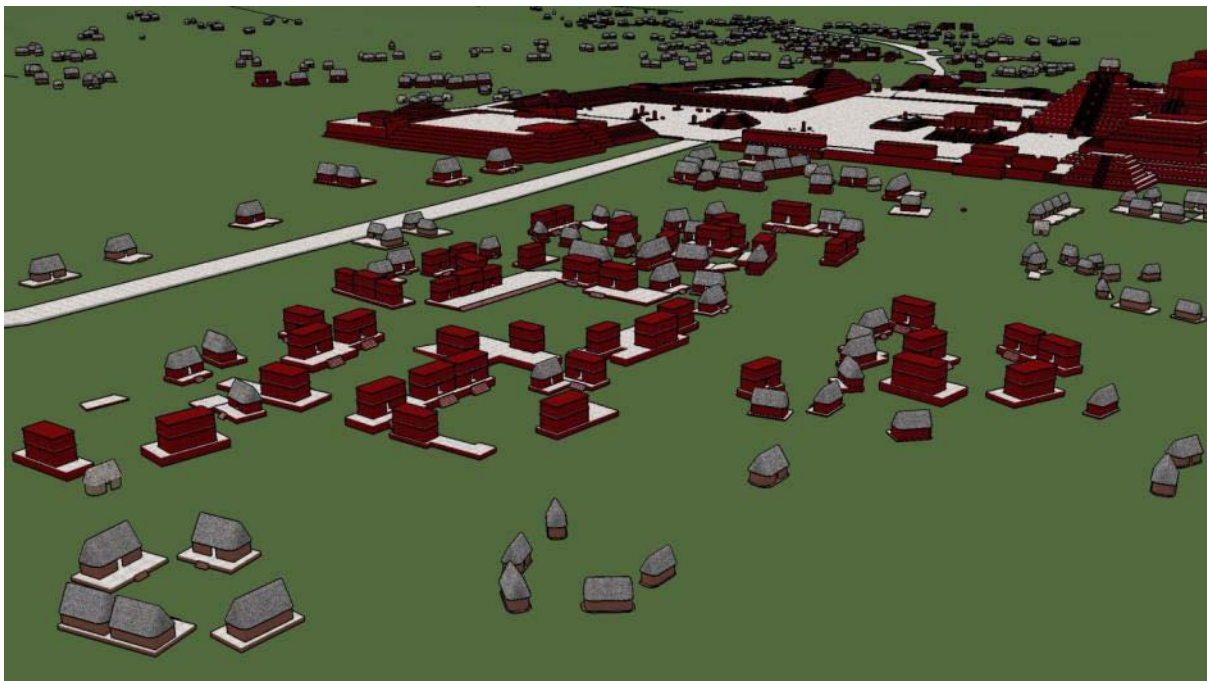


Figure 7. SketchUp Reconstruction of El Bosque suburb
—Principal Group and Las Sepulturas and Salamar suburbs in background—

Integration of Low Resolution Models into the Pipeline

The process of modeling continues; however, we have tested the pipeline to integrate these models into a virtual reality environment and UC Merced's collaborative environment. SketchUp Pro offers several export options for 3D models including *.dae (COLLADA), *.dxf, *.3ds, and *.obj. Our tests have determined that the Obj file format is compatible with both the landscape visualization program that we are using (Visual Nature Studio 3—VNS 3) and UC Merced's collaborative environment.

Dr. Aguiaro (FBK) has tested the Dxf format for the *QueryArch3D* tool and, while the models can be imported (or used) in the *QueryArch3D* environment, more tests of other file formats are necessary to determine which format is ideal. (Note—it is very important that the geometry of the SketchUp models is clean to ensure correct exporting from SketchUp to

*.obj and importing into other environments such as VNS 3.) Further research is needed to implement database storage procedures for the textures contained in the Obj files.

b. High Resolution, Reality-Based 3D Models — Sculptures & Architecture

One of the project objectives is to create the most complex and highly detailed 3D models possible in order to test the limits of technology and the prototype tool the project is developing. The architecture and sculpture from the reign of Copan's thirteenth ruler - King *Waxaklajuun U'baah K'awiil* (reign AD 695-738) were selected as the study sample. This includes Temple 22, on the East Court of Copan. During the Start-Up Level I project in 2009, project collaborators from ETH Zurich and FBK Trento acquired reality-based data to create 3D models of Temple 22 and East Court. One approach was to make 3D models of individual sculptures acquired with laser-scanning data, such as the corner masks of Temple 22, currently located in the Copan Sculpture Museum.



Figure 8: High resolution 3D model from laser scanning data of one of Temple 22's corner masks

The disadvantage of making such 3D models is that it is time-consuming and requires a high expertise level. It does not allow for hypothetical reconstructions and it represents a very heavy load for real-time, online use (60 million polygons).

The advantage of these techniques is the high resolution they offer –for the level of detail, and reproducibility, it is unmatched. It is highly accurate down to the millimeter and is a 3D record that documents quantitative information for researchers and allows students to virtually visit present-day archaeological sites and to explore architecture from varying angles.



Figure 9: Front and side view of high resolution 3D model of Copan Stela A from laser scanning data.

c. Hybrid Model of Temple 22

When it comes to using these 3D models to test out various hypothetical reconstructions of Temple 22's facades and to visualize how the building might have looked, things become more complex because the building is in ruins. The Temple 22 was a daring experiment in true masonry architecture (built without adhesive mortar), but once the protective plaster and paint wore off, its upper facades and sculpture collapsed. Today only the first story remains and it is hard for visitors to imagine the glory of this ancient temple. Over 3500 fragments of mosaic facade sculpture now housed both in Honduras and museum collections around the globe. The most famous of these is the Maya Maize God, the "Crown Jewel of Maya Art," now at the British Museum. Our goal is to scan representative sculpture pieces from the temple's façade that today are separated around the world and test out various hypothetical reconstructions as they might have appeared on the temple at the time of its construction in AD 715.

Therefore, this phase of the project tested the pipeline for how to build a highly-accurate, hybrid, 3D model or simulation of Temple 22 that will combine high-resolution, reality-based models of façade sculpture, with the low-resolution CAD simulation of the temple. The data being used are from von Schwerin's Temple 22 Façade Sculpture Analysis and Reconstruction Project (1998-present) and include:

- a. Building plans/elevations – 2D and 3D
- b. Preliminary reconstruction drawings
- c. 3D models of the East Court, Temple 22, and selected sculptures
- d. 2D drawings and photographs
- e. Sculpture database in Filemaker Pro with attributes

Because the goal of this phase of the project is to determine the pipeline for creating a full 3D reconstruction of Temple 22, the resulting 3D models shown below are tests of 3D reconstruction process can work. That is, they are not reconstructions of how the building might have once looked. We do intend to simulate a variety of hypothetical solutions to the reconstruction, and this work will begin when 3D models of a sample of the temple's façade sculpture are made.

Nevertheless, this preparatory work is unique because it integrates a variety of different data sources (range scans, images, and GIS data), and researches the best pipeline for the reconstruction process in anticipation of the 3D model being used in a variety of online research environments.

Methodology:

We had at our disposal already a geometrically-precise, CAD reconstruction of the temple in 3D Studio Max model that had been made of Temple 22 in 2001. This was made to determine and reconstruct the vault system and upper stories of Temple 22 (Ackeley and Ahlfeldt 2001). In that phase we scanned plans and elevations and used real textures. Our goal was to reconstruct and determine the building's vault system and upper stories, and to reconstruct the exterior façade sculpture. We were able to prove that there was a second

story on the building, and to determine and visualize the design of the vault system. But when it came to hypothetical reconstructions of the façade, the sculpture was the problem. How to render it in 3D? The attempt we made with photogrammetric reconstruction of sculpture was too boxy.

But how to simulate sculpture? To this end, the University of California, Merced was awarded a sub-award (PI: Maurizio Forte) by the present project to work with von Schwerin to construct the hybrid model. This consisted of two phases, first a hybrid, low-resolution model, designed for the collaborative system, and then a high-definition (heavy file) model to test the pipeline for making more detailed visualizations.

Phase 1

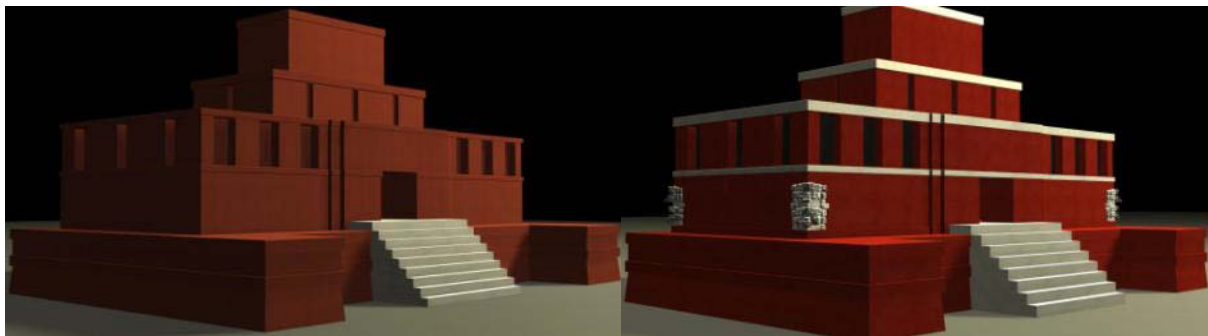


Figure 10: Temple 22 3D models. With (right) and without (left) selected sculpture details.

In 2010, Fabrizio Galeazzi (UC Merced) completed a new 3D model of Temple 22 based on the 3D Studio Max model from Laura Ackley made in 2001 and laser scan models of sculpture made by Fabio Remondino in 2009. To revise the 3D model Galeazzi adjusted the textures and measurements. There were some problems with the files: the unit scales were all wrong, probably due to the different 3D Studio Max versions used for the reconstructions. For example: the Temple 22 Basement's width was 398.50 meters, instead 28.60 meters. Therefore, Galeazzi had to rescale the models to the correct proportions. He updated all the models adding the new measures given to him by von Schwerin. To do this he used 3D Studio Max (Autodesk) and Adobe Photoshop was used to create the 3D model textures. He also implemented and optimized the 3D models of the corner masks and interior sculpted doorway of the temple, realized by Fabio Remondino, into the 3D model of the temple – thereby making this a hybrid model.

Galeazzi then worked to optimize the model for the real-time collaborative system by adapting the 3D model to the virtual reality engine. To be effectively visualized and used in the virtual reality engine, the model has to have specific characteristics. For this reason Galeazzi worked on the merging of all the model's vertexes, the analyses of the polygons normals, and, eventually, the cleaning of the redundant polygons and vertexes.

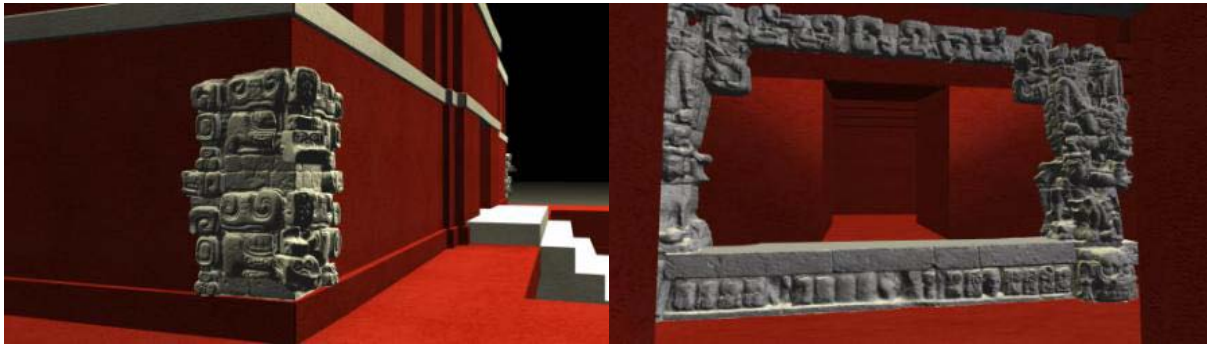


Figure 11: High-res 3D models placed onto the low-resolution CAD model of Temple 22: corner mask (left) and interior doorframe (right)

Regarding the 3D model's texturing, Galeazzi had to re-apply the textures using the *UVW map* and *Unwrap UVW* modifiers of 3D Studio Max, since the model was totally rescaled. He then worked on the creation of light and cameras for the renderings, prepared snapshots and a movie.

This resulted in a “blank canvas” that von Schwerin worked with Forte's team to test how to integrate high-resolution 3D models of the exterior façade sculpture onto the façade, and to make them lighter for use over the internet. The next step will be to make additional reality-based scans of about 100 pieces of representative sculptures to test different façade sculpture reconstructions for Temple 22 (Figure 11 and 12).

Phase 2- Preliminary High Definition Model.

Once the base model was created, we then created a preliminary High Definition model to test the pipeline. In 2011, Raúl Maqueda, in collaboration with the Virtual Heritage Lab of UC Merced, directed by Forte, prepared a higher definition 3D Model of Temple 22.

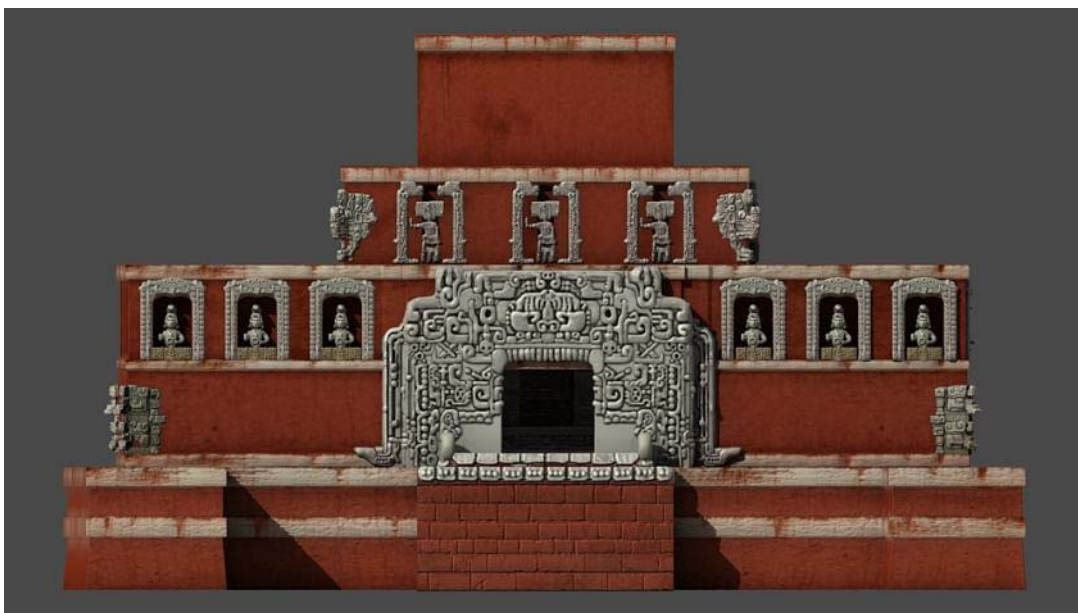


Figure 12: Preliminary High Definition Model of Temple 22 used to test the process of integrating various data sources into the reconstruction process

In the case of Copan's Temple polygonal modeling, the final result looks more detailed and accurate, but the time needed to create and texture such models is much longer than with objects created from shapes, primitives, or compound objects. We started from initial scaled base model, using von Schwerin's hypothetical reconstruction of the front elevation of the temple as a starting point. To model the initial shape is the preliminary step for further modeling. It is essential always to work with scaled and well fit shapes, to avoid multiplying inaccuracies in poorly scaled models.

Maqueda used *3D Studio Max* to handle the first Low Polygon model, exporting the meshed model as .obj archive to the program *Zbrush*. *Zbrush* allows one to generate thousands of polygons over the base mesh, and over this new high polygon mesh, to start to sculpt all the details inherent to the original model. *Zbrush* permits us to work on a model controlling the intensity, roughness, smoothness or whatever describes the objects. The modeled object is obtained through applying clay layers by means of brushes with alpha channels (transparency), so it is possible to control the digital drawing application at any moment in the making of the necessary details. The finished models modeled in *Zbrush* software have a perfect workflow with *3D Studio Max*, so we can export the file in .obj format to handle and place it in the correct point.

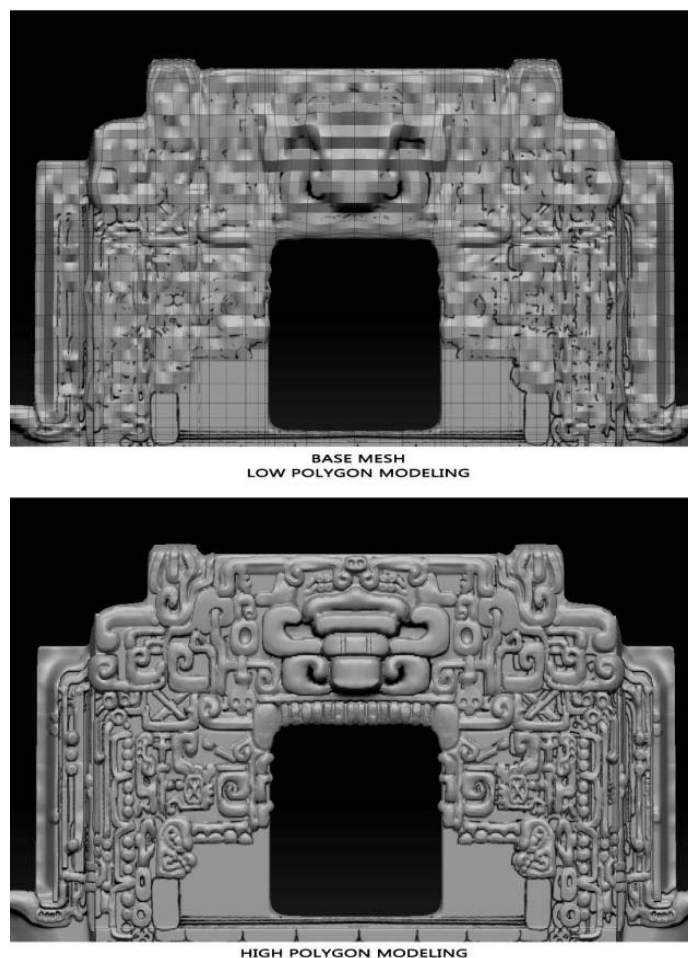


Figure 13: Visual Difference between Low Res (above) and High-Res model (below)

Texturing

Texturing is understood as the process of adding skin and properties to an object. We use UVW and Unwrap UVW Maps to texture our objects. This method involves the creation of a 2D map that is 'glued' to our 3D model with total control over the maps involved in the texturing phase.

As we use the Unwrap UVW method, it lets us assign mapping (texture) coordinates to objects and sub-object selections and to edit those coordinates by hand as well as with a variety of tools. We can also use it to unwrap and edit existing UVW coordinates on an object previously modified. We can adjust mapping to fit on Mesh, Patch, Polygon, and NURBS models using any combination of manual and several different procedural methods, with total control over the object.

When we have finished the High-Poly model, with the aim of not overloading the computer processing, we have to arrange High Definition Maps over Low Polygon models. The way to achieve this issue is by using Normal Mapping with Displace Information (Figure 14).

A Normal Map is a three-color map, unlike the gray-scale maps used for regular bump mapping. The red channel encodes the left-right axis of normal orientation, the green channel encodes the up-down axis of normal orientation, and the blue channel encodes vertical depth.

As mentioned before, we had two different kinds of models from Copan's Temple 22:

- 1) the model of the building itself, divided into different levels (the base with the stairway, and the three stories or levels from the temple that are low polygon models)
- 2) the high definition models of decoration related to the temple (Maize god, Corners, Mouth door, niches, and scanned data).

The way we have to handle those two different models are directly related to the definition of the polygon modeling. In Low Polygon models, we have to unwrap different parts of the model to texture in Photoshop. In this step is important to achieve the best possible texture divided in different layers to have a perfect control over the final view of the element. But not only is the basic skin of the model important, it is also important to get a good Bump map and a Specular map so we can transmit the properties of the material. Specular and bump maps are always gray scale maps, so we have to convert the original map into gray scale and hide some of the layers we did for the Diffuse Map (Figure 15).

In the case of the second kind of models, High Polygon ones, the method to get the texture is a bit different. As we have a very high resolution polygon model, we have to get the right texture. As we said before, Normal bump mapping is a way of adding high-resolution detail to low-polygon (Low Poly) objects. It is especially useful for real-time display devices such as game engines, and it can also be used in rendered scenes and animations, but has a high proficiency in Virtual Reality or On-Line Information. This is the way we have textured the

high polygon models of Copan's temple. This workflow, although a bit slower and hard to achieve, makes easier to handle in final render animations or in real-time applications

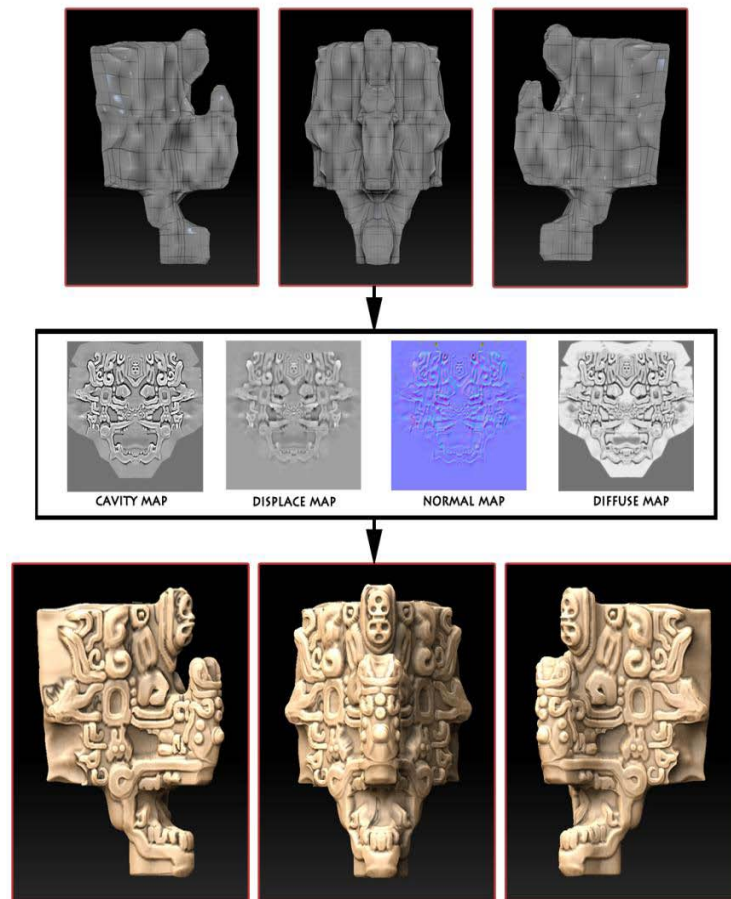


Figure 14: Arranging HD maps over low poly models shown with a Temple 22 corner mask.

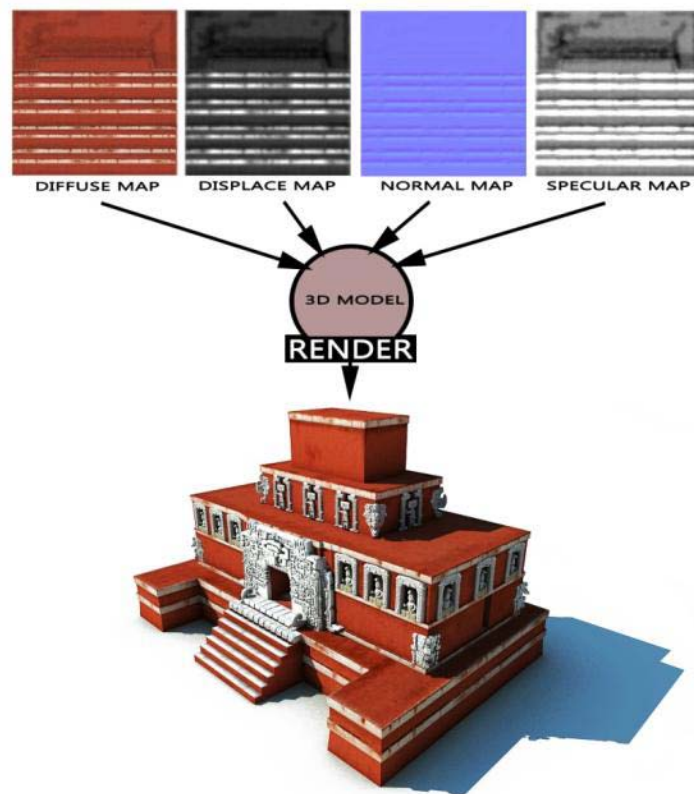


Figure 15: The merging of different maps and final rendering result shown on Temple 22 model

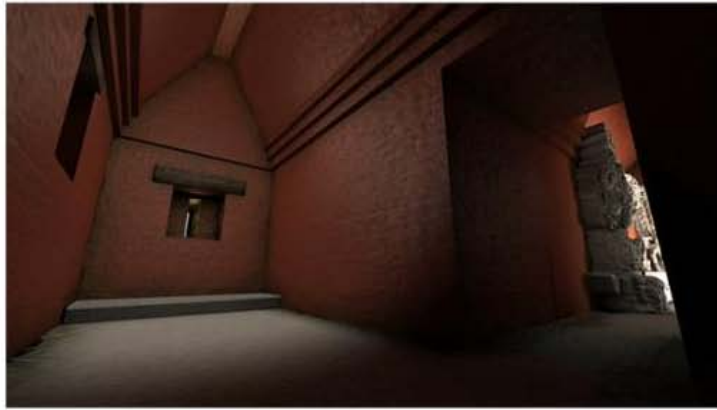
Illumination

Exterior lighting is usually the last step in developing a scene in 3ds Max before rendering the final product. All further work on the image or animation is usually done with compositing and editing programs. We try to plan lighting strategies at the start of the project so we can keep them in mind when developing textures and materials for the scene. The Daylight and Sunlight systems create outdoor lighting that simulates sunlight based on location and time of day, month and year. Different kinds of light objects cast light in different ways, emulating different kinds of real-world light sources, so we can have total control over the scene, providing direct illumination as well as rebound or global illumination (GI), as a way to provide real physical illumination.

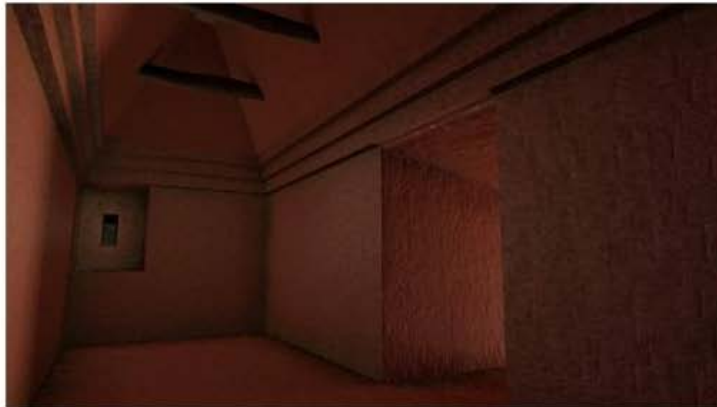
When placing lights in the scene, it is important to consider several factors, including the size of the scene, the number of objects, the possibility of breaking down the rendering into layers for compositing, and the visibility of objects and their color in areas of shadow. Knowing all the factors is vital for determining which global illumination (GI) solution is most suitable and how bright the GI should be. Additional lights can be used if required, for example if we need to focus attention on a particular object, but then you need to optimize the light settings in order to use less system resources and render faster.

For inside views it was a bit more complicated. As we have the Main Door entrance, we had to simulate the light of the sun distributing itself to the hall and the different chambers

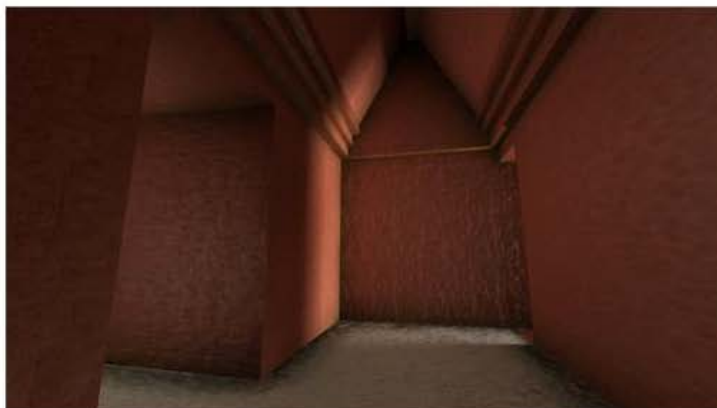
(West, North and East). But as interior views, we had to simulate with other indirect light the Global Gathering illumination, to get the accurate interior lighting (Figure 16).



WEST ROOM



NORTH ROOM



EAST ROOM



DOORWAY

Figure 16. Simulated lighting for interior rooms of the temple



EXTERIOR VIEWS

Figure 17: Various views of the current High-Definition version of the Temple 22 Reconstruction made to test the working process. Only the corner masks are generated from laser-scan data. The other sculptures were made to look three-dimensional based upon 2d drawings as explained above.

The resulting hybrid model that was constructed in this work is quite large, in terms of resources consumed. Some scenes are difficult to work with and render with anything less than 8GB RAM, and at least a mid-range processor and graphics card. Moreover, the maps used during the creation of this project are very high resolution, with some over 4000 pixels in the smallest dimension. Large maps can consume immense amounts of RAM, usually equivalent to their uncompressed versions.

Applied Online Research Applications for these 3D Models

- 1) One major use of this 3D model is a testing ground for von Schwerin's reconstruction work. Von Schwerin continues to work with Forte's team to integrate the high-resolution 3D models of the exterior façade sculpture onto the façade, and to make it lighter for use over the internet.
- 2) The implementation of the model of the temple in a new, real-time, collaborative, immersive virtual environment (UC Merced's Teleimmersive System) created by Forte's team in collaboration with UC Berkeley is another final goal for this model (Forte, Kurillo, 2010, a-b-c). The goal of the teleimmersive system is to implement and share in a 3D immersive cyberspace models, actions, and dbases by multiple locations. We have tested the model of the Temple 22 in 2 Teleimmersive Systems (Berkeley and Merced) and in the Powerwall at UC Merced (Figure 18 and 19). The Powerwall is a large high-resolution retro-projected display wall able to display in stereo and equipped with a motion tracking system. Either way, if the project will be adequately supported in the future, scholars in the USA, Germany, and Honduras will be able to work collaboratively, simultaneously and remotely in a virtual space to discuss and test the placement of sculpture on the temple façades and create multiple reconstructions.



Figure 18. Testing the model of Temple 22 in the Teleimmersive System

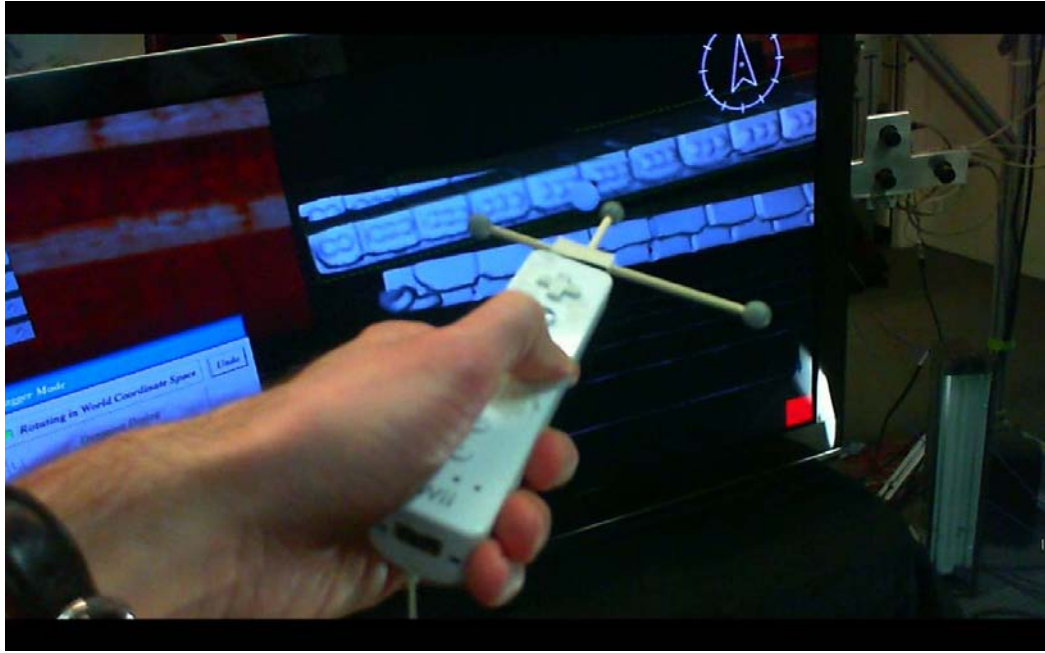


Figure 19. Manipulating the individual sculpture elements within the Teleimmersive system for the façade reconstruction process.

3)

This model was also then tested by FBK for inclusion in the *QueryArch3D* system. It was segmented in queryable sections and optimized for use in the system (Figure 20, 23, and 25).

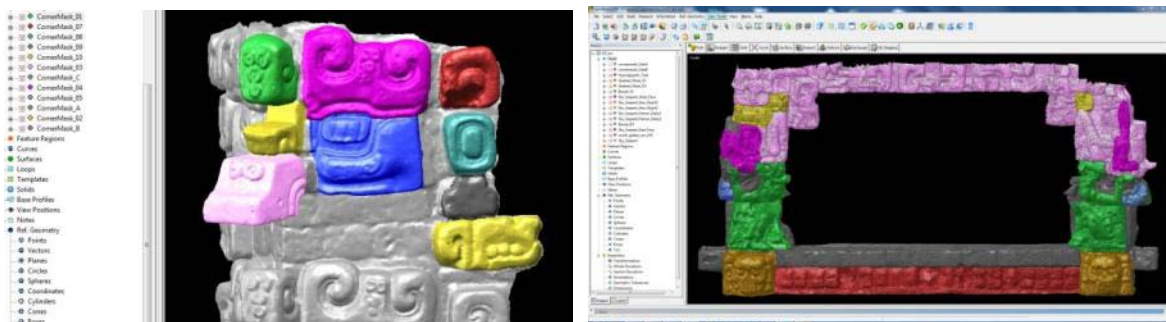


Figure 20: These high resolution models of sculpture motifs were also segmented for use with the database query capabilities in *QueryArch3D*.

III. Virtual Reality (VR)

3D modeling is a powerful tool, but a 3D model by itself lacks important context information. We can obtain this context by combining data from different sources. In our pipeline, we combine our 3D models with surveying data (e.g., GIS, photogrammetric and laser-scanned models), panoramic images, videos, and 3D reconstructions. One important component of this data integration is virtual reality.

In October 2010, Dr. Richards-Rissetto began to develop a virtual reality environment of Copan's early ninth century landscape. She is using a landscape visualization program—Visual Nature Studio 3 (VNS 3)—to integrate the low resolution 3D models of the built environment imported from SketchUp (as *.obj files) with natural landscape features including terrain, hydrology, and vegetation.

While VNS 3 is not free or open source, we chose it as the landscape visualization software for three reasons. First and foremost, it imports GIS and geospatial data and tools to control visualization directly from GIS data—this speeds the visualization process and maintains spatial reference, preserving spatial integrity of the 3D models in the natural landscape, which is essential for spatial analysis, i.e. using the VR for research purposes. Second, it offers several formats for export to test and use in the *QueryArch3D* tool and UC Merced's collaborative environment. Third, it offers many automated tools and customizable options to create 3D vegetation and realistic terrain.

Using a free downloadable 3D viewer—NatureViewExpress—researchers, educators, and students can navigate the VR; however, the VR is not linked to a searchable database. Our goal is to replace *QueryArch3D*'s current interface of 3D schematic models with this VR model so that users can query the Copan GIS (database) as they navigate through Copan's reconstructed landscape. By linking to a searchable database and performing attribute and spatial queries, users will be able to identify patterns and explore social, political, ideological, and environmental relationships in a navigable virtual environment. Such functionality is not possible using currently available software.

To replace the 3D schematic models with the VR, we need to identify the appropriate export format from VNS 3 to *QueryArch3D* (and UC Merced's collaborative environment). VNS 3's Scene Express 2 extension exports the VR landscape into several formats including *.kml/*.kmz (Google Earth), GIS data, VRML, FBX (can be loaded into Maya), OpenFlight, and *.3ds/*.prj (3D Studio Max/Viz). This step in the pipeline is not finalized, but we will soon test the feasibility of using *.3ds files as Dr. Agugiaro has already identified a way to bring 3D Studio Max files (*.3ds) into the *QueryArch3D* Tool and Dr. Forte has also tested .3ds files (using the Temple 22 model) in the collaborative environment.

Developing the VR is an ongoing process. Currently, the VR contains architecture imported from the SketchUp model—a preliminary model of the Principal Group and approximately 700 structures from the urban core. It also contains terrain generated from the GIS Digital Elevation Model and some hydrological features that are also generated from the GIS data. Figures 21 and 22 illustrate the Copan VR—the architecture, terrain, and hydrology are accurate, however, the vegetation is hypothetical (i.e., not based on paleo-environmental

data). Along these lines, Dr. Richards-Rissetto has begun to gather paleo-environmental data to identify the types of 3D vegetation models that need to be created for Copan's early ninth century landscape. VNS 3 populates vegetation across the landscape based on criteria such as slope, slope direction (north, south, east, west), density, proximity to water, or soil type. These criteria can be exchanged to model different environmental scenarios. Moreover, while the current VR focuses on the early ninth century, in the future we plan to include additional temporal components, which will allow researchers to illustrate and explore shifts in water and landscape management over time, or to test contradictory settlement and environmental scenarios of Copan's decline. Linking the VR to the GIS will allow archaeologists, art historians, and others to explore space-time relationships across ancient landscapes in new and creative ways, leading not only to new findings but also fostering new questions and avenues of exploration.



Figure 21. Virtual Reality Environment (work in progress)—View facing northeast of urban core

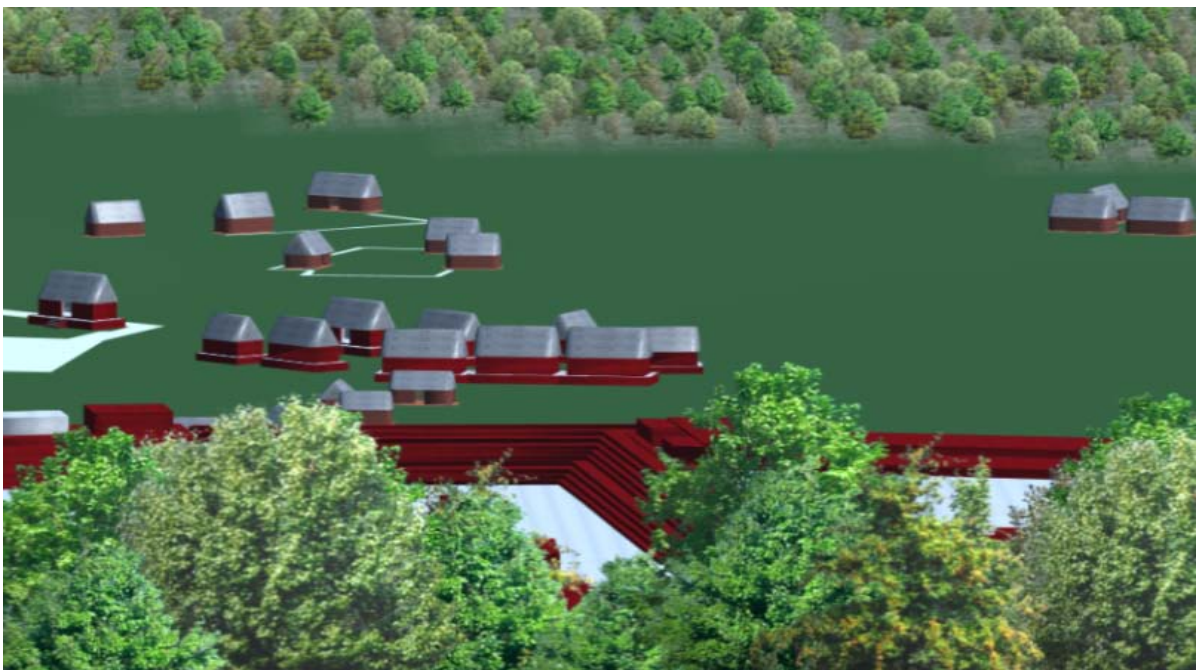


Figure 22. Virtual Reality Environment—View facing north and overlooking Principal Group

IV. Databases and IT

In Phase I of the MayaArch3D Project, Dr. Richards-Rissetto and Dr. von Schwerin worked with Dr. Martin Sauerbier (ETH Zurich) on the conceptual framework for the database (see von Schwerin et al. 2009). Dr. Sauerbier's initial database tests identified two approaches suited to linking 3D models with query functionality—(1) CityGML and (2) PostgreSQL with PostGIS (von Schwerin et al 2010). After further tests, Dr. Giorgio Agugiaro (FBK), the developer of *QueryArch3D*, decided to use the PostgreSQL option. The following section explains why Dr. Agugiaro did not use CityGML and why he chose to use PostgreSQL.

CityGML is an information model for the management and visualization of 3D urban objects. It defines the classes and relations for the most relevant topographic objects in cities and regional models with respect to their geometrical, topological, semantic and appearance properties. It also deals with generalization hierarchies between thematic classes, aggregations, relations between objects, and spatial properties (Kolbe, 2009). While CityGML describes how to structure data, it does not represent a storage system itself: as a matter of fact, data is currently stored in a text-based file, based on .gml format, but the implementation in a proper DBMS is left to the user. Therefore, this is not suitable for our needs. We need a database to properly store data.

Another problem with CityGML is that its highest available level of detail (LoD) defines architectural models (including interiors) by means of their constructive elements and with a maximal point accuracy of 0.2 m. These specifications are of course enough for modern buildings; but, understandably, they are not (yet) compatible for reality-based archaeological models, which generally differ in terms of scale and scope.

PostgreSQL in combination with the spatial enhancement PostGIS was chosen for the project for the following reasons:

1. It is free and open source software (FOSS).
2. Analogously to other DBMS, using a database facilitated the reduction of heterogeneity of data formats to allow for data integration.
3. Its PostGIS extension allows for storage of spatial data in same database.
4. Using PHP as a scripting language the database content can be accessed via websites in read and write mode. While direct access to the tables can be implemented by means of forms embedded into HTML-websites, a suitable interface (i.e., *QueryArch3D*) needed to be developed for graphical access from a 3D viewer.

In terms of database development for the MayaArch3D Project, Dr. Agugiaro has determined the pipeline for importing and exporting standard GIS formats from/to PostgreSQL (e.g. using ArcGIS and its Data Interoperability extension or, alternatively, by means of the open-source OGR utilities via QGIS) and a way to use the *.obj file format to import triangulated 3D geometries.

Next Steps for the Database

1. Database enrichment and extension. Fill in the DB with archeological data/info and more high resolution models into the tool.
 - a) One major planned improvement consists in adding more models at LoD2 to LoD4, and consistently enriching the attributes related to the entities.
 - b) texture and chromatically characterize the structures
 - c) replace the prismatic models in QueryArch3D with the SketchUp models
 - d) add hydrological features and vegetation to QueryArch3D
 - e) segment the stelae and the hieroglyphic texts
2. Improve or add import/export routines for PostgreSQL.
3. Storing Textures. Further research is needed to define a data model, to implement database storage procedures for the textures contained in the *.obj files.
4. Integrate Filemaker Pro data of Temple 22 sculpture into *QueryArch3D* tool (i.e., PostgreSQL database)

Regarding the database storage system, some import/export routines to/from PostgreSQL should be added and/or improved. For example, converting a GIS polygon (with holes in it) into a triangulated mesh is not yet a straightforward process with the existing tools. PostGIS, in its present version (1.5.2) offers support to store 3D features, but all GIS functions are still substantially 2D, i.e. three-dimensional “out-of-the-box” spatial analysis tools are still to come. On the other hand, the coming 2.0 version, due in spring 2011, should offer substantial improvements in raster data management and storage for TINs and meshes.

V. Prototype Tool - QueryArch3D

QueryArch3D is a prototype for a new platform for an online, searchable repository that can bring together GIS maps, 2D and 3D files of archaeological data, and virtual environments for teaching and research on ancient architecture and landscapes.

The development of the QueryArch3D tool was led by Dr. Giorgio Agugiaro at the 3D Optical Metrology Research Group, Bruno Kessler Foundation, Trento, Italy (Agugiaro et al. 2010). It is currently held on their server and will be transferred to the UNM server by September 2011.

As stated above, the goal of the project was to develop a tool that curates and searches not only 2D digital collections (drawings, maps, diagrams, text, photographs, and videos) but also queries 2D and 3D attributes including highly accurate 3D scans of sculpture via a virtual environment of Copan's ancient landscape. In the development of the *QueryArch3D* tool, we kept in mind existing technological limitations and defined four characteristics that a tool useful for analysis in Cultural Heritage should be able to perform:

1. Handle 3D multi-resolution datasets,
2. Allow queries based both on geometries and on attributes,
3. Support 3D visualization/navigation of the models, and
4. Permit both local and on-line access to the contents.

These four characteristics guided our development process, which was split into four successive steps:

- I. Definition of a conceptual schema for multiple levels of detail (LoDs) and adoption of geometric and semantic hierarchies,
- II. Check and structure existing data according to LoDs and hierarchies,
- III. Data homogenization and integration
- IV. Development of the visualization environment and query tools on the front-end.

Step I.

In order to cope with the complexity of multiple geometric models, we defined a conceptual scheme for multiple LoDs. The *QueryArch3D* tool uses multiple LoDs to manage and deal with independent data collection processes and different data resolutions. LoDs facilitate efficient visualization and data analysis. For the data from Copan, we defined four levels of detail for the structures—the higher the LoD rank, the more detailed and accurate the 3D model. For example, LoD1 contains simple prismatic models, and LoD4, contains (high resolution) reality-based models (Figure 23).

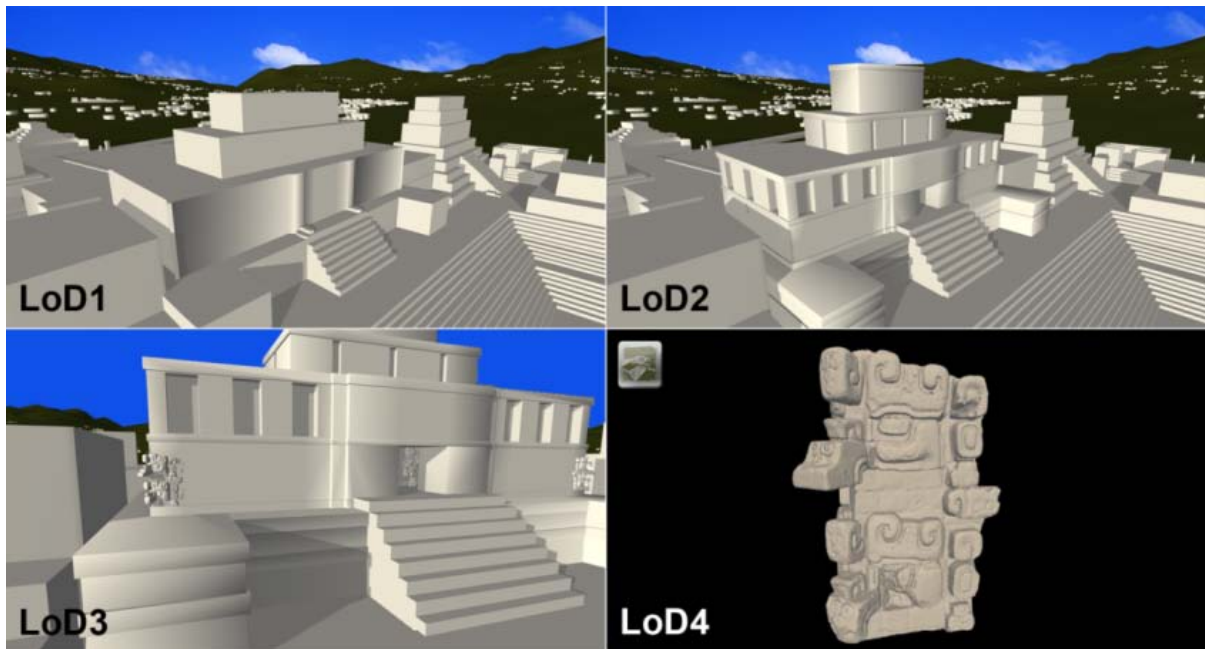


Figure 23: Different levels of detail (LoD) in the QueryArch3D tool, Temple 22 models. Clockwise from top-left: LoD1 with prismatic geometries, LoD2 with more detailed models (only exterior walls), LoD3 with interior walls/rooms and some simplified reality-based elements, LoD4 with high-resolution reality-based models.

The adoption of a LoD-dependent hierarchical schema required the contextual definition of semantic and geometric hierarchical schemas. This was achieved by an accurate identification and description of the so-called “part-of-relations”.

At the semantic level, we needed to define structures and their architectural elements (components). For example, we had to address questions such as: What is a temple or a palace? How is it characterized? What are its components? Defining the semantic schema is essential because entities (or structures in this case) are comprised of features (stairs, rooms, etc.) that are described by attributes, relations, and aggregation hierarchies (part-of-relations) between features.

Step II.

Once the semantic hierarchy is established, its elements need to be linked to the corresponding geometries. This operation requires that we structure the geometric models to comply with the hierarchy, by means of data aggregation, disaggregation, and segmentation. For example, the GIS data needed to be edited to replicate the semantic hierarchy so that we could use the GIS attributes to properly segment the resultant 3D prismatic models generated from the GIS data. As for the attribute data, we confirmed that no fields were empty and that every feature was properly assigned to a corresponding structure, group, etc.

Step III

After the segmentation process was completed, homogenization and data integration could be performed. The data homogenization process confirms that both attribute and geometric data from different sources have compatible structures and semantics so that data integration can occur. All geometric models—that is, the GIS data, Temple 22 (Studio Max Model), the corner mask, the stelae, and Temple 22's door frame (photogrammetric models and laser scans)—in the DTM were aligned in order to spatially “fit” together and georeferenced in order to share the same coordinate system. This step is important especially when integrating data from multiple sources and resolutions into a single environment (or tool).

We chose PostgreSQL as the Database Management System (DBMS) to store and manage data for three key reasons. First, it reduces data format heterogeneity, which means that data originally stored in multiple formats such as *.txt, *.dxf, *.shp, *.kml is all stored in PostgreSQL. Second, its PostGIS extension, allows us to store spatial data in the same database, providing a valuable (and unique) data management system. Third, it is open source.

Step IV

For data administration purposes, a simple front-end based on Microsoft Access 2010 and relying on Access Runtime 2010, was developed so that project members could access and edit the QueryArch3D database online.

After identifying the limitations of CityGML (see above), we adopted Unity 3D, a game engine, for of the interactive 3D visualization and query front-end. One of the major reasons that we chose Unity 3D was that applications can be developed for online use—a free plugin is available to access contents embedded in a webpage. In addition, Unity 3D can be developed for all major platforms including Windows, Linux, Mac OS X, PS3, XBOX, Wii, iPhone. Along these lines, using Unity 3D as the 3D engine, the *QueryArch3D* tool could deliver content in three ways:

- 1) stand alone on a single PC (this requires an installation DVD),
- 2) completely online embedded in webpage (this requires a free plugin), and
- 3) a hybrid using an installation DVD to access the geometries (of 3D models), and online access to the database (attributes and 2D data such as photographs and maps).

In terms of navigation, three modes are available:

- a) *aerial view* over the whole archaeological site
- b) *ground-based walkthrough* mode, in which the user can approach and enter a structure on foot and
- c) *detail view* (see Figure 25, bottom right).



Figure 24. Navigation modes for the QueryArch3D tool: [left] aerial view displaying LoD1 models only, [right] walkthrough mode, with mixed LoD1-to-LoD3 models. An example of the detail view for LoD4 models is given in the next figure (bottom-right).

While navigating the 3D environment, users can perform attribute queries (e.g. “highlight all structures built by a ruler X” or “highlight only stelae belonging to group Y and built in year Z”). Users can also perform standard queries-on-click: once a geometric object is selected, the related attribute values are shown in a text box. The amount of retrieved information is dependent on the LoD: for LoD1 structures, only global attributes are shown, while for higher LoDs also the detailed information is shown, according to the selected segment.

Users can make the typical searches that you would expect of an archaeological database. For instance, they can obtain results as a standard table or call up photos or drawings, but instead of doing this via search fields or a hyperlinked map, users can access these data by clicking on the 3D models in the VR landscape. In additional—and that is truly cutting-edge—*QueryArch3D* allows for uniquely 3D queries at multiple scales. Users can do distance-dependent object queries in which the kind of information received about an object changes according to the distance from which an object is being viewed. The next three slides illustrate this functionality.

For far-distance queries, you see the low-resolution schematic 3D models and when you click on a model you access general information about the structure. For mid-distance queries, a more detailed model is visualized, for example, Temple 22, of which we can query individual subparts. We can continue this process to arrive at some very high resolution models of sculpture. For example, while approaching Temple 22 from afar, at first the corner masks are invisible. Then they are visualized as a whole, and then they can be queried “stone by stone” for information on iconographic motifs, excavation information, etc. Furthermore, you can perform queries on the attributes of every geometric object (structure, altar or stela) in the 3D environment. For example, you can choose to highlight all “stelae” or all “Type 4 structures” and everything belonging to this category will be highlighted in 3D.

Finally, distances between two objects in the 3D world can be measured, and simple line-of-sight tests between two selected objects can be conducted.



Figure 25. Different data interrogation modes in QueryArch3D. [Top-left] Query by attributes and display of the results in terms of geometries. [Top-right and bottom] LoD-dependent queries on geometric models: at LoD1, only global attributes are shown, for LoD2 to LoD4 models also subparts can be selected and more detailed information is retrieved.

Conclusions and Future Work—QueryArch3D

QueryArch3D fulfills the four initial requirements; however, it is still at a prototype stage and is subject to further developments and improvements.

The following research directions and steps are anticipated:

1. Improve LoDs.
2. Improve graphic user interface (GUI).
3. Add/integrate more archaeological data from external database.
4. Increase spatial queries. Some spatial functions (like distance measurements and line-of-sight) have already been implemented. More capabilities such as viewshed analysis and proximity measures will be added in the future.
5. Refine the segmentations of Temple 22 and the Great Plaza Stelae.
6. Set up UNM as the Institutional Host for QueryArch3D tool and MayaArch3D Project website (managing and maintenance).

PROJECT OUTCOMES

Our most significant outcomes were:

- 1) **We have developed a prototype tool – *QueryArch3D*. This tool is unique because** it is a web-based tool that allows users to query 3D models via a navigable VR environment—as users virtually navigate through an ancient landscape they can click on architecture to call up data that are linked to a database. **It will be available in September for testing on** www.mayaarch3d.unm.edu.
- 2) **The tool is a modular system that allows for unlimited growth.**
- 3) We determined that **Unity 3D—a game development tool— was the ideal software/platform** for interactive visualization because it is customizable and allows us to develop interfaces between database and VR.
- 4) **We have developed new high and low resolution 3D models—a 3D model of T22, expanded SketchUp of Copan’s architecture, and begun to develop a VR of the Copan valley.**
- 5) We have **successfully tested the model of the Temple 22 in real time in the Teleimmersive system** loading 2 million polygons.
- 6) We have **begun to identify the types of specific research questions that can be addressed using the prototype.**
- 7) **All project partners agree that this is a stimulating and important project that generates new research in all project areas** (GIS, VR, 3D modeling, databases)
- 8) **It is a great “crash test” for the technologies**, for issues of sustainability, and in terms of how to standardize processes.
- 9) In 2010 and 2011, the project participants gave **presentations at conferences and workshops around the world** to Mayanist scholars and technology specialists about the project results to date—in the US (Philadelphia, Sacramento), Honduras (Tegucigalpa), Italy (Trento), Germany (Bonn, Cologne), Sweden (Umea), China (Xi’an), and Sevilla (Spain). These presentations elicited great interest and enthusiasm. Common questions centered around about replicability and specific research questions that will be addressed.

We learned that:

- 1) We need an IT professional – a database expert must be added to our team.
- 2) We need student researchers to enter and create data (e.g. GIS data and SketchUp models) now that the pipeline and templates have been established.
- 3) This type of cross-disciplinary project requires close collaboration with computer scientists and archaeologists and IT professional from the very beginning.

Conclusion

In sum, 3D, GIS, and virtual reality technologies are revolutionizing the connection between user and object. They make available and allow us to experience space-time parameters in a dynamic environment that until recently were only possible through direct experience in real space. Today's 3D technology makes "immersive" experiences possible on home computers without requiring expensive hardware and software equipment. Information can be dispersed through varied media (e.g., CD-ROM, internet, mobile devices, and hybrid tools), thus fostering the circulation and comparison of ideas. Tools like QueryArch3D can be easily tailored to these varied media and provide a wide range of users from researchers to educators to cultural resource managers with a virtual reality experience that links 3D models to queryable archaeological data.

NEXT STEPS

In Fall 2011, we will begin **testing and evaluation** of *QueryArch3D* by making it available for beta testing via the dedicated website on the UNM server. After compiling and analyzing the initial results, we will be ready to present the *QueryArch3D* prototype, as well as the 3D Model of Temple 22 to be used in the Teleimmersive Environment and gain in-depth feedback.

A financing plan for the extended project is being developed, and we have identified three possible **applied collaborative research projects** that would employ these models and this tool:

- 1) A collaborative research grant is planned between von Schwerin and Richards-Rissetto on social experience, architecture, and landscape at eighth-century Copan.
- 2) A project to test and further develop UC Merced's Teleimmersive system through the partners of the project.
- 3) A project with UC Merced and the VIAS-Vienna Institute for Archaeological Science University of Vienna (Dr. Georg Zotti) have begun to test our 3D models and landscape for a new plugin in Stellarium—a free open source planetarium software program that shows the map of the sky georeferenced in different periods of time. The program can be set to visualize the night sky in the past so we are using this functionality to develop and test new research questions about Copan's ancient architecture and landscape.

The **current research challenges** that the next phase of our project will address are:

- 1) Linking VR environments to GIS
- 2) Textures—determine how to store textures in the PostgreSQL database
- 3) Improving and adding import/export functionality between geometry and attributes
- 4) Add functionality to *QueryArch3D*, especially geographic or locational queries
- 5) Data Administration. Access to the data for administration purposes (updates and maintenance) is realized by means of a Microsoft-Access-based front-end, but its tighter integration/embedding in the Unity-based front-end (under a proper rights administration) would be useful.
- 6) Issues of management (contributions and access) and security for online use.

DISSEMINATION

PROJECT EMAIL and WEBSITE

The project contracted Meadow Design (San Francisco) to construct a project website that has its own URL on the UNM server.

EMAIL Address: maya3d@unm.edu

URL: www.MayaArch3d.unm.edu

Project Publications:

G. Agugiaro, F. Remondino, G. Girardi, J. von Schwerin, H. Richards-Rissetto, R. De Amicis
2011 A Web-based Interactive Tool for Multi-Resolution 3D Models of a Maya Archaeological Site. In: *Proceedings of the 4th ISPRS International Workshop 3D-ARCH 2011: "3D Virtual Reconstruction and Visualization of Complex Architectures" Trento, Italy, 2-4 March 2011*. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVIII-5/W16 (on CD-ROM).

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2011 (in press)

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Project Publications in preparation:

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2010 Social Inequality at Late Classic Copán, Honduras: Modeling Mobility in GIS. Paper presented at *109th American Anthropological Association Annual Meeting*, Nov. 18, 2010, New Orleans.

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2011 "Transforming 2D maps into 3D landscapes: Visualizing the ancient Maya city of Copan, Honduras". Seminar at Department of Historical, Philosophical and Religious Studies, Umeå University, Sweden. April 14, 2011.

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2011 Visualizing Copan: 3D Perspectives from an Ancient City. Paper presented at the 76th Annual Meeting of the Society for American Archaeology, Sacramento California, April 2011.

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2011 The Greeks of the New World. Institute of Archaeology, University of Freiburg, February

von Schwerin, J., H. Richards-Rissetto, F. Remondino, and G. Agugiaro

2011 3D Patrimonio Cultural en Copán, Honduras. Paper presented at the VIII Congreso Centroamericano de Antropología, Los Retos de la Antropología en Centroamérica: Identidades, Diversidad Cultural y Procesos Políticos, Feb. 24, 2011, Tegucigalpa, Honduras.

Project Workshops

April 2009	<i>International Workshop in 3D Archaeology and Cultural Heritage Management in Honduras.</i> April 17-18, 2009, Copan, Honduras. 80 participants from over 10 countries.
January 2009	<i>3D Copan Project Workshop</i> May 29, 2009 Technical University of Zurich (ETH, Zurich). 16 participants from five countries.
November 2010	QueryArch3D Design Workshop, Freiburg
May 2011	MayaArch3D Workshop, DAI/U Bonn, Bonn
September 2011	MayaArch3D Workshop, UNM, Albuquerque (planned)

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Seoul, South Korea. Best Paper Award, VSMM 2010.

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